VARIATIONS IN RAINFALL.

By EDWARD A. BEALS.

Rudyard Kipling is quoted as having recently said:

The United States by its haste and waste has so dissipated its resources that before national middle age it is driven to seek virgin fields for cheaper food and living.

It is true to a certain extent that the United States has been prodigal with its natural resources, but we are now awakening to the importance of the trust imposed upon us, as witnessed by the growing importance of the annual meetings of the National Conservation Congress. Great Britain has been even slower than the United States in conserving her natural resources, for it was not until the last meeting of the British Association for the Advancement of Science that this question came before that body for a full discussion of the subject. The president of that association at the recent meeting in Portsmouth, England, devoted a large part of his address to the necessity of conserving the natural resources of Great Britain; and while the proceedings of this meeting have not yet been published it is very likely the steps taken there will inaugurate a new policy in the preservation of some of the most important resources of that country.

Of all the good things with which nature supplies us I know of none more important than water. It is the life of the land, and we should be thankful that the greater portion of our country receives a liberal supply. The water that we are most interested in is evaporated from the oceans and deposited in the form of rain or snow on the land. The rainfall or snowfall of a country therefore is the base upon which to calculate the feasibility of irrigation projects, power plants, and farming operations in general. Nothwithstanding the importance of the subject I find in my talks with people from day to day that there are many who have very limited ideas regarding precipitation. They seem to think that the amount that falls every year is about the same, and if it is not the climate of that locality is changing for better or worse, as the case may be.

I wish to show by Weather Bureau and other records that while there are large variations in rainfall from year to year that our climate is not changing to any appreciable extent, and, if possible, give a clearer understanding of the limitations of these records. Prof. Henry, of the Weather Bureau, by means of careful comparisons, has arrived at the conclusion that the rainfall records in our large cities may show values anywhere from 5 to 10 per cent short of the true amount.[1] These errors are due to the exposures of the rain gages, which vary as regards elevation and the proximity of tall buildings. A difference in elevation means a difference in wind velocity, and the proximity of tall buildings creates eddies and currents that are unnatural. When there are artificial eddies and strong wind currents around a rain gage the catch is not so great as otherwise would be the case. The ideal exposure is in an open clearing some little distance from surrounding trees which act as a wind break without being near enough to create disturbing eddies.

Ideal exposures are not to be found in our large cities, but great pains are taken to find the best that can be had for all Weather Bureau gages. Every once in a while the changing conditions in cities make it necessary to obtain new exposures, and then there is an uncertainty as to the correction that should be applied to make the records at the two exposures strictly comparable. A rain gage exposes an aperture about 8 inches in diameter which is supposed to catch all the rain or snow that falls over that area. This rain or snow is then measured, and the record thus obtained is said to represent the amount that falls over a relatively large section of the surrounding country. It often happens that it rains very hard in one portion of a city while no fall of consequence takes place in another part of the same city. It is assumed that in the long run these variations will be equalized by the catch in a single location, although gages located near one another may not agree by considerable in the amounts caught for single months or even years.

Carefully kept precipitation records are the only information we have on which to base conclusions regarding the changes in the amount of rainfall from year to year, and from the tables and charted results that will be shown one will be able to draw his own conclusions as to whether or not the rainfall in the United States is increasing or diminishing.

Before discussing these records, however, I wish to call attention to a very important discovery that was made by Prof. Brückner about a quarter of a century ago. Prof. Brückner, in studying the remarkably long-period oscillations in the water level of the Caspian Sea, came to the conclusion that there is a 35-year period of climatic oscillation. The records of the gage heights of the rivers feeding the Caspian Sea showed the same oscillations as the sea itself, which proved the rise and fall was not due to subterranean sources.

With the Caspian Sea record as a starting point Prof. Brückner obtained a record of the time of harvesting grapes in southern France from about the year 1400, a record of ice in the rivers from 1736, the occurrence of severe winters from the year 800 and such information as was available about the variations in Alpine glaciers for the last 400 years. This information was compiled and the results confirmed his previous conclusions that there is an oscillation in the climate of the world with an average swing from one maximum to another of 35 years. The periods vary in length from time to time and individually are frequently shorter or longer, but 35 years is the average of a great number of them as determined by Prof. Brückner. The cause of these oscillations is unknown, but some scientists think they are connected with a long-period variation in sun-spot frequency.

After the fact was established that oscillations take place in climate the next point to ascertain was the amount of the changes in measurable units. Prof. Brückner collected all the long-period temperature and rainfall records available in the world and from them determined that there are places where the phases and epochs are reversed, but the average between the maximum and minimum was nearly 2° for temperature and might be in some localities as much as 50 per cent for rainfall. It is greatest in the interior of continents and least near their coasts. It has not yet been demonstrated that this information can be used for forecasting purposes, as

[1] See Annual Report of the Chief of the Weather Bureau, 1896-97, p. 319.

the areas of reversals have not been mapped, and the variations in the length of the periods are so great that it is impossible to foretell when the changes will occur.

The periods, which are taken from Moore's Descriptive Meteorology, are as follows:

TABLE I.—*Oscillations of climate according to Brückner.*

Years.	Temperature ° C.	Rain (per cent).	Lakes.	Beginning of Alpine glacier movement.
1731–1735	−0.34	−4		1735 advance.
1736–1740	−0.43	+9	1740 max.	
1741–1745	−0.35	−6		
1746–1750	+0.45	+5		1750 retreat.
1751–1755	+0.16	+5		
1756–1760	−0.08	−3	1760 min.	
1761–1765	−0.10	0		
1766–1770	−0.42	−4		1767 advance.
1771–1775	+0.24	+7		
1776–1780	+0.15	−2	1780 max.	
1781–1785	+0.18	−2		
1786–1790	−0.11	+2		
1791–1795	+0.46	−2		
1796–1800	+0.07	−1	1800 min.	1800 retreat.
1801–1805	+0.26	−4		
1806–1810	−0.18	+3		
1811–1815	−0.46	0		1814 advance.
1816–1820	−0.35	0	1820 max.	
1821–1825	+0.56	−2		1823 retreat.
1826–1830	+0.14	0		
1831–1835	+0.03	−8	1835 min.	
1836–1840	−0.39	−5		1840 advance.
1841–1845	0.00	+1		
1846–1850	−0.08	+3	1850 max.	
1851–1855	+0.11	+1		
1856–1860	+0.06	−4		1856 retreat.
1861–1865	−0.06	−5	1865 min.	
1866–1870	+0.11	−1		
1871–1875	−0.04	+2		1875 advance.
1876–1880	−0.07	+7	1880 max.	
1881–1885	−0.08	+6		

Means for the earth as a whole: The positive and negative values represent variations in the mean temperature and the annual rainfall, respectively, in the latter case in percentages of the mean annual amounts.

In compiling rainfall data we are at once confronted with the question as to the true normal, or, in other words, a normal that will not change appreciably, no matter how long the record has been kept. It[1] is claimed that a rainfall record of 25 years may give averages as much as 5 per cent too high or too low, and a record of 40 years may depart as much as 3 per cent from the true normal. The longest record considered in this paper extends back about 100 years and the shortest covers a period of only 36 years. It is safe to say that the 100 years' record will give us approximately a true normal, but in the case of the shorter ones the true normal has not yet been established, and the one used may be anywhere from 1 to 3 per cent too high or too low.

To show the unsatisfactory character of a 10-year record of rainfall, I have compiled the means for every 10 years at Astoria and The Dalles, beginning with the first year of the record, then dropping the first year and obtaining the mean for the next 10 years, and so on until the mean for the last 10 years has been obtained. These means are shown in Table II, in the last column, and it will be seen that some of them are over 15 per cent above and some are equally short of the average for the whole period covered by the observations. The Astoria mean for the 10 years ending in 1880 was 85.16 inches and for the 10 years ending in 1891 it was only 64.24 inches. At The Dalles the variation was from 17.74 inches for the 10 years ending in 1884 to 12.54 inches for a similar period ending in 1889.

In order to smooth out accidental extremes in yearly amounts due to local storms and other causes Blandford's method of obtaining five-year means was used for obtaining data for the curves on plate 1. His formula is as follows: $\frac{a+4b+6c+4d+e=c'}{16}$ where c' is the progressive average of the middle year of the group. Table II, which follows, contains the yearly and progressive averages for Astoria and The Dalles, Oreg., and on plate 1 will be found curves representing the progressive averages at these stations. On plate 1 curves also have been drawn for the progressive averages in southeastern New England and the middle Mississippi Valley. They are reproductions of those prepared by Prof. Mead and published in Bulletin No. 425 of the University of Wisconsin. Prof. Mead used Weather Bureau data in preparing his curves, and the tabular data are omitted, but they can be readily obtained from the Weather Bureau by those who wish to pursue this investigation farther.

For southeastern New England the means of 3 stations were used, viz, Boston, New Bedford, and Providence, and for the middle Mississippi Valley the means of 4 stations, viz, Muscatine, Monticello, Marengo, and Peoria, while for the Oregon curves the progressive averages are from single stations. It is evident the means of 3 or 4 stations will represent the average conditions in a locality better than the mean of a single station, provided the climatic conditions are similar in the selected locality. Unfortunately, there are no long rainfall records in Oregon in similar climatic districts that can be combined, and the single record at Astoria probably presents more irregularities than would be the case had it been possible to combine this record with others in the same neighborhood. The curve at The Dalles does not show marked departures from the normal, because of the small rainfall at that station combined with the stability of the climate.

TABLE II.—*Yearly rainfall, progressive averages, departures from the normal, and 10-year averages.*

ASTORIA, OREG.

Years.	Annual amount (inches).	Progressive averages (inches).	Departures (inches).	10-year averages (inches).
1854	59.22			
1855	79.20			
1856	59.17	69.60	− 8.3	
1857	79.82	70.65	− 7.2	
1858	63.36	72.37	− 5.5	
1859	82.15	75.11	− 2.8	
1860	70.65	78.06	+ 0.2	
1861	92.93	87.69	+ 9.8	
1862	61.32	78.91	+ 1.0	
1863	94.13	80.69	+ 2.8	74.20
1864	75.70	83.33	+ 5.4	75.84
1865	85.22	87.57	+ 9.7	76.44
1866	100.40	90.11	+12.2	80.57
1867	91.25	83.43	+ 5.6	81.71
1868	57.74	72.59	− 5.3	81.15
1869	69.61	70.32	− 7.6	79.90
1870	71.19	77.42	− 0.5	79.95
1871	100.42	82.88	+ 5.0	80.70
1872	73.70	80.85	+ 3.0	81.94
1873	74.41	78.81	+ 0.9	79.96
1874	80.89	82.77	+ 4.9	82.62
1875	95.73	87.19	+ 9.3	81.53
1876	84.75	85.23	+ 7.4	79.97
1877	83.64	79.52	+ 1.6	79.21
1878	56.88	80.41	+ 2.5	79.12
1879	108.30	88.87	+11.0	82.99
1880	92.88	91.09	+13.2	85.16
1881	89.40	79.79	+ 1.9	84.06
1882	52.43	63.51	−14.4	81.93
1883	50.71	53.57	−24.3	79.56
1884	49.38	52.99	−24.9	76.41
1885	56.16	60.23	−17.6	72.45
1886	71.59	71.29	− 6.6	71.14
1887	92.09	77.19	− 0.7	71.98
1888	68.73	73.18	− 4.7	73.16
1889	65.03	66.81	−11.1	68.84
1890	58.49	66.30	−11.6	65.40
1891	77.74	71.07	− 6.8	64.24
1892	70.01	77.82	− 0.1	65.99
1893	91.68	83.37	+ 5.5	70.09
1894	88.84	84.22	+ 6.3	74.04

[1] See p. 326, Annual Report Chief of the Weather Bureau, 1896–97.

Table II.—*Yearly rainfall, progressive averages, departures from the normal, and 10-year averages*—Continued.

ASTORIA, OREG.—Continued.

Years.	Annual amount (inches).	Progressive averages (inches).	Departures (inches).	10-year averages (inches).
1895	70.75	83.49	+ 5.6	75.50
1896	94.82	84.36	+ 6.5	77.82
1897	85.06	83.54	+ 5.7	77.12
1898	68.72	83.62	+ 5.7	77.11
1899	101.40	86.63	+ 8.8	80.75
1900	84.97	86.38	+ 8.5	83.49
1901	77.87	83.08	+ 5.2	83.41
1902	86.48	81.45	+ 3.6	84.97
1903	74.81	81.25	+ 3.4	83.37
1904	88.67	80.69	+ 2.8	83.36
1905	72.63	79.38	+ 1.5	83.54
1906	82.73	76.74	− 1.1	82.33
1907	73.91	71.69	− 6.2	81.22
1908	56.71	68.64	− 9.2	80.02
1909	73.21	....	....	77.20
1910	86.85	....	....	77.39
Means	77.31	77.88	....	....

THE DALLES, OREG.

1875	26.40	....	....	....
1876	15.34	....	....	....
1877	17.53	16.79	+2.0	....
1878	13.53	16.65	+1.9	....
1879	21.55	17.33	+2.6	....
1880	13.61	17.79	+3.0	....
1881	21.92	17.74	+3.0	....
1882	15.53	16.80	+2.0	....
1883	14.15	15.76	+1.0	....
1884	17.81	15.04	+0.2	17.74
1885	11.95	14.03	−0.8	16.29
1886	13.80	13.06	−1.7	16.14
1887	12.21	12.17	−2.6	15.61
1888	11.69	10.94	−3.8	15.42
1889	7.51	10.30	−4.5	14.02
1890	12.18	10.95	−3.8	13.88
1891	12.12	12.18	−2.6	12.90
1892	11.97	13.90	−0.9	12.54
1893	17.97	15.86	+1.1	12.92
1894	18.02	16.52	+1.7	12.95
1895	13.88	16.06	+1.3	13.14
1896	16.76	15.50	+0.7	13.43
1897	16.60	14.22	−0.6	13.87
1898	7.58	13.08	−1.7	13.46
1899	16.74	12.60	−1.2	14.38
1900	13,62	14.81	0.0	14.53
1901	15.83	15.54	+0.8	14.90
1902	17.43	15.78	+1.0	15.44
1903	12.77	15.86	+1.1	14.92
1904	19.94	15.63	+0.8	15.12
1905	11.79	15.17	+0.4	14.91
1906	14.84	15.29	+0.5	14.71
1907	20.08	15.04	+0.2	15.06
1908	8.18	13.94	−0.8	15.12
1909	16.05	....	....	15.05
1910	14.56	....	....	15.15
Means	15.10	14.79	....	....

In southeastern New England a dry period began in 1834 that lasted until 1858 or a quarter of a century. The periods about 1838 and 1848 were unusually dry, averaging, in 1838, 9 inches below normal and in 1848, 8 inches below. Between these two periods there were a few years when the deficiency was only 4 inches. This long dry spell was followed by one with moisture above the average which lasted until 1894, or for 36 years. During all of this time the rainfall in southeastern New England was normal or above normal, and in 1888–1890 it was 7 or more inches above normal, being practically as much above normal in 1888–1890 as it was below during the two extremely dry periods in 1838 and 1848.

Since 1894 the fluctuations have not been so marked, being below normal for about 3 years to 1897 and then above normal until 1905. Since 1905 there has been a deficiency in the rainfall of southeastern New England. The curve showing the averages in southeastern New England illustrates how the people living at the time of the Mexican War had good reason to believe that their rainfall was diminishing, for it had been below normal since 1834, and it continued below normal for about 12 years afterwards. The people of a later day in that locality, however, would most naturally have believed they were getting more rain than formerly, as the amounts averaged above normal from 1858, with the exception of a very few years, to 1905.

The maximum and minimum periods of rainfall in southeastern New England do not correspond with Brückner's periods, although there are minor fluctuations that accentuate these periods and they would have a bearing in computing the means of the world in favor of the claims made by Prof. Brückner.

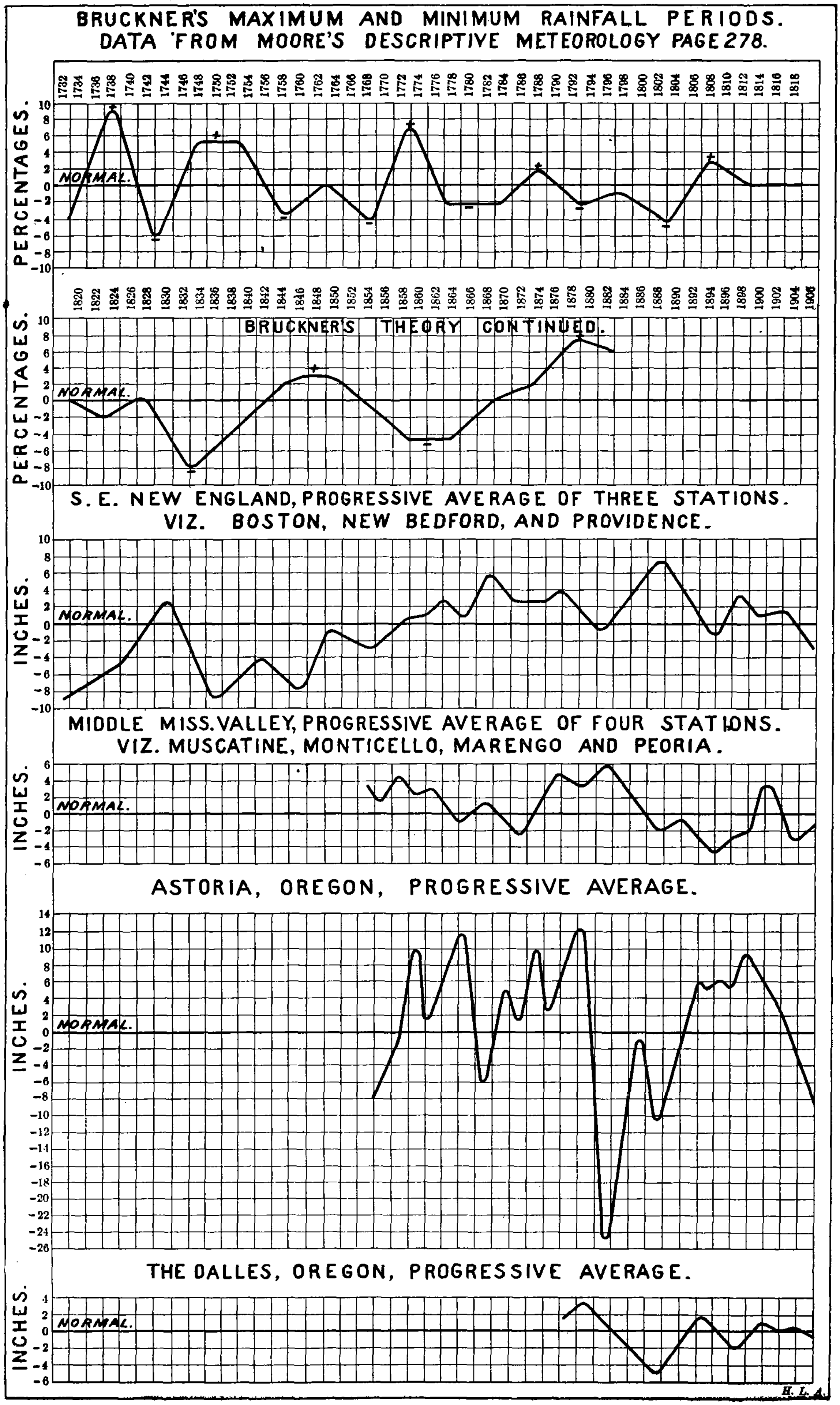
In the middle Mississippi Valley curve, as well as those which follow, we are met with the difficulty of shorter records, which make our normals less reliable.

We find in the middle Mississippi Valley the rainfall was 4.5 inches above normal in 1858, and then it decreased somewhat irregularly until 1873, or for 16 years. In 1874 an increase took place, which was progressive, excluding minor fluctuations, until 1882, when the amount was 5.5 inches above normal. The yearly amounts then diminished quite uniformly until 1889, in which year there was a deficiency of 2 inches. The variations for the next 2 years were small, but in 1893 the curve started downward and the minimum was reached in 1895, when the amount was 5 inches below normal.

After 1895 the rainfall in the middle Mississippi Valley increased until 1902, which was a wet year, with a progressive average a little over 3 inches above normal. From 1902 to date there has been a gradual decrease in rainfall, and the curve ends with a departure of 2 inches below normal. The middle Mississippi Valley curve shows some resemblance to the curve depicting Brückner's departures above and below normal, and confirms his statement that the changes are more marked in the interior of continents than they are near the coast.

The Astoria curve shows that from 1858 to 1882, 24 years, the rainfall was above normal, except for a very short period central about the year 1869, when it was 6 inches below normal. During this long period with an excess in rainfall there were years when it amounted to over 10 inches, and then again it was very nearly normal. This maximum period at Astoria includes both a minimum and a maximum period in the curve established by Brückner, and therefore does not correspond with the Brückner curve any more than does the curve during the same years in southeastern New England. Beginning in 1883, a deficiency in rainfall took place which lasted until 1892, 10 years. The rainfall was scant in 1883, when the departure was as much as 25 inches. From 1892 until 1907 there was a marked excess over the usual amount, and this period would correspond with one of Brückner's deficiency periods if his curve were extended to include these years. Since 1907 there has been a deficiency in the rainfall at Astoria.

The curve at The Dalles is more symmetrical. It shows a maximum period beginning with the first observation and lasting until 1885. From 1886 until 1893, 8 years, there was a deficiency, and since then the curve shows 2 short periods with the rainfall above normal, 1 short period with it below, and the beginning of another with it below, the length of which is problematical. The Dalles station is in the interior and the climate can be classed as continental. The curve shows characteristics similar to Brückner's and to the one for the middle Mississippi Valley, with the distinction that the periods at The Dalles are apparently a year or two in advance of those in the middle Mississippi Valley. This may be important, for if a law instead of a coincidence, then it will be possible to make long-range predictions of rain-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PERCENTAGES.
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S. E. NEW ENGLAND, PROGRESSIVE AVERAGE OF THREE STATIONS.
VIZ. BOSTON, NEW BEDFORD, AND PROVIDENCE.
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INCHES.
NORMAL.
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NORMAL.
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INCHES.
NORMAL.
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fall in the middle Mississippi Valley based upon data previously collected in the interior of Oregon. Such a conclusion, however, can not be reached until the records cover a much longer period.

The main facts to be gathered from these curves are that our supply of rainfall varies greatly, and that there are long periods when the amount is above normal and long periods when it is below. There is apparently no permanent change taking place, notwithstanding the depletion of our forests and the greatly increased area that has come under cultivation. It is true that many of our small lakes have disappeared, but we will have to look for other causes than a diminished rainfall to account for this phenomenon, and to my mind the most plausible is the filling in of the bottoms that takes place where the vegetation is rank in summer and is later killed by the winter's cold. This, together with the drifting soil, soon fills shallow lakes with swamp muck until they are of insufficient depth to hold water, when the soil dries out and makes excellent farming land.

The curves on plate 1 are deserving of careful study, for if by their past behavior we can judge their future course, we can predict wet and dry periods several years ahead, and such predictions would be of incalculable value to the growing industry known as "dry farming," as well as to all other farming operations. It is in the semiarid regions where slight departures from the normal precipitation are of vital importance, as there are many sections where "dry farming" can be made a success only during periods when the precipitation is above normal. As we have shown, the precipitation sometimes continues above normal for many years before the pendulum swings the other way, and we should make the most of our opportunity during these years, and not waste our time and energy in trying to accomplish what is impossible during the dry years.